

RELAP5-3D User Problems

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Bechtel BWXT Idaho, LLC*

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1.0 Introduction

The Reactor Excursion and Leak Analysis Program with 3D capability¹ (RELAP5-3D) is a reactor system analysis code that has been developed at the Idaho National Engineering and Environmental Laboratory (INEEL) for the U. S. Department of Energy (DOE). The 3D capability in RELAP5-3D includes 3D hydrodynamics² and 3D neutron kinetics^{3,4}. Assessment, verification, and validation of the 3D capability in RELAP5-3D is discussed in the literature^{5,6,7,8,9}. Additional assessment, verification, and validation of the 3D capability of RELAP5-3D will be presented in other papers in this users seminar. As with any software, user problems occur. User problems usually fall into the categories of input processing failure, code execution failure, restart/re-nodalization failure, unphysical result, and installation. This presentation will discuss some of the more generic user problems that have been reported on RELAP5-3D as well as their resolution.

2.0 Unphysical Result 1

In running a modified Edwards-O'Brien pipe problem^{10,11} (correct initial temperature profile, modified nodalization to match gauge stations), break flow oscillations were observed. These oscillations were not observed in the installation Edwards-O'Brien pipe problem.

Studies showed that the oscillations go away by removing the transition 2 (junction void fraction in the range 0.1 to 0.15) underrelaxation between the original two-phase density ratio ($JCAT_{j,TP}$) and the old time throat density ratio (JCATO). Figure 1 shows the results of the Edwards-O'Brien test run on RELAP5-

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3D version 130 ('130' in the figure) and on RELAP5-3D version 130 with the improved choking model smoothing ('130+' in the figure). Verification and validation consisted of also running the INEEL test, the Marviken tests, the GE level swell tests, the Wyle test, and the Zion-1 PWR small break calculation (typpwr) from the RELAP5-3D assessment library¹².

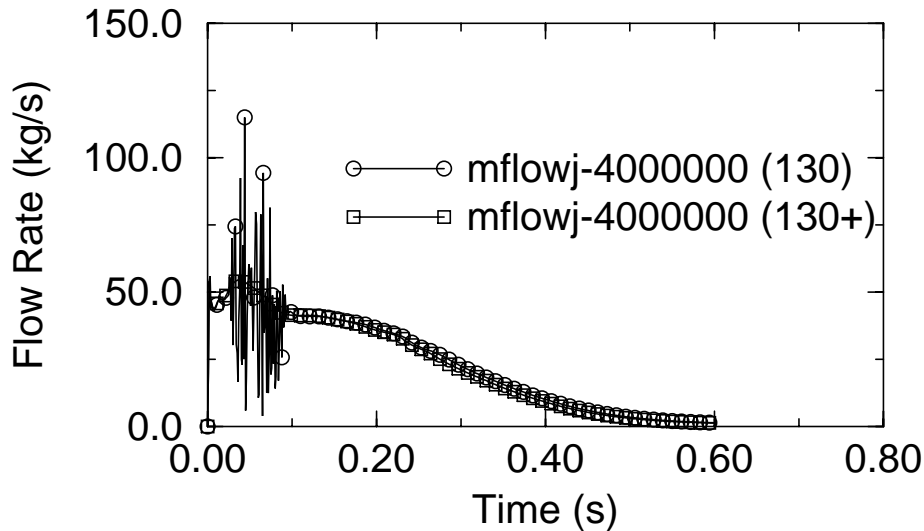


FIGURE 1. Edwards-O'Brien test mass flow rate.

3.0 Unphysical Result 2

A Kursk (RBMK) calculation showed a small temperature change across one of the air gaps compared to other air gaps. The problem was simplified to 4 volumes, 2 junctions, and 1 heat structure (26 mesh points). Spread sheet and MathCad calculations show that the radial source distribution is different than RELAP5-3D.

The RELAP5-3D radial source input was input incorrectly. The input was modified to use radial peaking factors that will be multiplied by volume weights. This then gave results that agreed with the spread sheet and MathCad results.

Additional words and equations were included in Volume II (main body and Appendix A) of the manual to clarify the radial source input. The additional words and equations are as follows:

Volume II, main body:

As discussed in Volume I, the integral of the internal volume source for the one-dimensional form of the transient heat conduction equation over the two sub-volumes on either side of a mesh point gives

$$\int \int_V S(\bar{x}, t) dV \approx P_f P(t) (Q_{lm} \delta_{lm}^v + Q_{rm} \delta_{rm}^v)$$

The term P_f is the factor that relates the reactor power (or power from a table or control variable) to the heat generation rate for a particular heat structure. Word 2 in the heat structure cards 1CCCG701 through 1CCCG799 is used to enter P_f . The term $P(t)$ is the time varying function that may be reactor power, power from a table, or power from a control variable. The volume weights δ_{lm}^v and δ_{rm}^v are shown in Volume I, Section 4.1. The space dependent terms for the left and right intervals, Q_{lm} and Q_{rm} , are calculated from

$$Q_{lm} = \frac{Q_{lm, input}}{\sum_m Q_{lm, input} \delta_{lm}^v + \sum_m Q_{rm, input} \delta_{rm}^v}$$

$$Q_{rm} = \frac{Q_{rm, input}}{\sum_m Q_{lm, input} \delta_{lm}^v + \sum_m Q_{rm, input} \delta_{rm}^v}$$

where the summation is over all the space mesh points for a particular heat structure. The space dependent input terms for the left and right intervals, $Q_{lm, input}$ and $Q_{rm, input}$, are entered in Word 1 ($Q_{i, input}$ for the i^{th} interval) of heat structure cards 1CCCG301 through 1CCCG399. The input terms $Q_{lm, input}$ and $Q_{rm, input}$ are relative values only; that is they are normalized by the summations in the denominator to obtain the final Q_{lm} and Q_{rm} terms. It should also be noted that the input terms $Q_{lm, input}$ and $Q_{rm, input}$ are multiplied by the volumetric weights δ_{lm}^v and δ_{rm}^v in the summations in the denominator.

Volume II, Appendix A, Cards 1CCCG301 through 1CCCG399, Heat Structure Source Distribution Data (Radial):

These cards are required if Word 1 of Card 1CCCG100 is zero and must not be entered otherwise. The card format is two numbers per set in sequential expansion format for $np-1$ intervals. The card numbers need not be in sequential order. Radial power peaking factors are entered here for the internal volumetric heat source (See Volume II, Section 3.1).

The description for W1(R) is next described.

Source value $Q_{i,input}$. These are relative values only and can be scaled by any non-zero factor without changing the results (See Volume II, Section 3.1). By entering different values for the various mesh intervals, a characteristic shape of a power curve can be described. If all the source variables are zero, there will be no internal heat generation for the heat structure geometry.

4.0 Unphysical Result 3

A 3D hydrodynamic system calculation with heat structures showed the heat transfer hydraulic diameter (heated equivalent diameter) used in the wall heat transfer correlations was set to the wrong volume hydraulic diameter. The user had specified 0.0 for the heat transfer hydraulic diameter (Cards 1CCCG801-1CCCG899 and 1CCCG901-1CCCG999, Word 1), which means the volume hydraulic diameter is used for this variable. The code was using the volume hydraulic diameter for the x-coordinate; it should have been using the volume hydraulic diameter for the z-coordinate.

Subroutine IHTCMP was modified to use the volume hydraulic diameter based on the value of F (Cards 1CCCG501-1CCCG599 and 1CCCG601-1CCCG699, Word 1, of the form CCCXX000F for one-dimensional and CCCXYYZZF for multi-dimensional if the word specifies a hydrodynamic boundary volume number).

Currently, if the value of F is 0 or 4, the volume coordinate associated values, used in the wall heat transfer correlations, such as the phasic volume velocities (used in the mass flux) are taken from the x-coordinate; if F is 2, the volume coordinate associated values, used in the wall heat transfer correlations, are taken from the y-coordinate; if F is 1, the volume coordinate associated values, used in the wall heat transfer correlations, are taken from the z-coordinate. Currently, the value of F was not used for the volume hydraulic diameter; the x-coordinate volume hydraulic diameter was always used. With this change, the value F is also used to specify the volume hydraulic diameter (used in the heat transfer hydraulic diameter).

Volume II, Appendix A of the manual was also changed to reflect this change in the code.

5.0 Code Execution Failure 1

A 3D hydrodynamic system calculation with heat structures showed the boundary condition types 3xxx and 4xxx (Cards 1CCCG501-1CCCG599 and 1CCCG601-1CCCG699, Word 3) do not work. The calculation fails in subroutine HTCOND.

Debugging pointed to an error in subroutine HTCOND. This subroutine was modified to pull out only the table ordinal from the packed word HTBNTS. This is needed to obtain the offset/index to the general tables.

In debugging and reading the coding, it was noticed that boundary condition types 3xxx and 4xxx can only be used if the boundary volume number or general table word (Cards 1CCCG501-1CCCG599 and 1CCCG601-1CCCG699, Word 1) specifies a boundary volume to obtain the sink temperature. The case when a boundary volume is not specified appears to be not coded. This was tested on a modified Bennett's heated tube calculation. The calculation ran, however debugging subroutine HTCOND shows that the wall heat transfer coefficient partitioning was in error since there is no attached volume but the subroutine is using a volume void fraction (variable VOIDG) which is an incorrect real number.

An update was developed to subroutine HTCOND that uses 1/2 for the partitioning if there is no boundary volume (as is done for boundary condition type 2xxx). Volume II, Appendix A was modified to reflect these changes.

The following table (Table 1) shows the available options for Cards 1CCCG501-1CCCG599 and 1CCCG601-1CCCG699, Words 1 and 3:

Table 1: Boundary condition options.

Word 3	Word 1 = 0 Symmetry or Insulated	Word 1 > 0 Boundary Volume	Word 1 < 0 General Table
0	$q_w = 0$ $h_w = 0$	-----	-----
1 or 1nn	-----	correlations for h_{wf} and h_{wg}	-----
1000	$T_w =$ $T_{\text{sink}} = 0$	$T_w =$ $T_{\text{sink}} = \alpha_g \rho_g$ $+ \alpha_f \rho_f$	$T_w =$ T_{sink} from table in Word 1
1xxx	$T_w = f(\text{time})$ $T_{\text{sink}} = 0$	$T_w = f(\text{time})$ $T_{\text{sink}} = \alpha_g \rho_g$ $+ \alpha_f \rho_f$	$T_w = f(\text{time})$ T_{sink} from table in Word 1

Table 1: Boundary condition options.

Word 3	Word 1 = 0 Symmetry or Insulated	Word 1 > 0 Boundary Volume	Word 1 < 0 General Table
2xxx	$q_w = f(\text{time})$ $q_{wg} =$ $(1/2)q_w$	$q_w = f(\text{time})$ $q_{wg} = \alpha_g q_w$	$q_w = f(\text{time})$ $q_{wg} =$ $(1/2)q_w$
3xxx	$h_w = f(\text{time})$ $h_{wg} =$ $(1/2)h_w$ $q_w = h_w(T_w - T_{\text{sink}})$ $T_{\text{sink}} = 0$ $q_{wg} =$ $(1/2)q_w$	$h_w = f(\text{time})$ $h_{wg} = \alpha_g h_w$ $q_w = h_w(T_w - T_{\text{sink}})$ $T_{\text{sink}} = \alpha_g T_g + \alpha_f T_f$ $q_{wg} = \alpha_g q_w$	$h_w = f(\text{time})$ $h_{wg} =$ $(1/2)h_w$ $q_w = h_w(T_w - T_{\text{sink}})$ T_{sink} from table in Word 1 $q_{wg} =$ $(1/2)q_w$
4xxx	$h_w = f(T_w)$ $h_{wg} =$ $(1/2)h_w$ $q_w = h_w(T_w - T_{\text{sink}})$ $T_{\text{sink}} = 0$ $q_{wg} =$ $(1/2)q_w$	$h_w = f(T_w)$ $h_{wg} = \alpha_g h_w$ $q_w = h_w(T_w - T_{\text{sink}})$ $T_{\text{sink}} = \alpha_g T_g + \alpha_f T_f$ $q_{wg} = \alpha_g q_w$	$h_w = f(T_w)$ $h_{wg} =$ $(1/2)h_w$ $q_w = h_w(T_w - T_{\text{sink}})$ T_{sink} from table in Word 1 $q_{wg} =$ $(1/2)q_w$

6.0 Code Execution Failure 2

A code failure occurred while trying to run a design calculation for a supercritical pressurized light water reactor (a Generation IV reactor). The pressure was set to 25 MPa (which is above the critical pressure 22.12 MPa) with a time-dependent volume at the exit. The flow was set with a time-dependent junction at the inlet. The inlet temperature was initially set below the critical temperature (647.3 K) and ramped to a value over the critical temperature. The code failed on a water

property error when the fluid temperature became approximately 655 K.

The 'fillpcr' thought problem (loops over the critical point with a high pressure of 90 MPa) was run; this still runs as it did on earlier versions. When the 'fillpcr' problem was changed to a high pressure of 25 MPa, it also fails like the design calculation at 655 K due to a water property error. A series of 27 'fillpcr' problems (high pressures range from 90 MPa to 22.2 MPa) were also run; 20 out of 27 of these problems failed.

Modifications [includes some suggestions by John Tolli (INEEL)] to the steam tables, the interpolation subroutines, subroutine STATEP, and subroutine FWDRAG allow the user's original input deck (25 MPa) and all 27 'fillpcr' input decks to run.

Figures 2 - 4 show pressure versus temperature plots for the 'fillpcr' calculations with no code updates (no modifications). The saturation line is also shown in each of the figures.

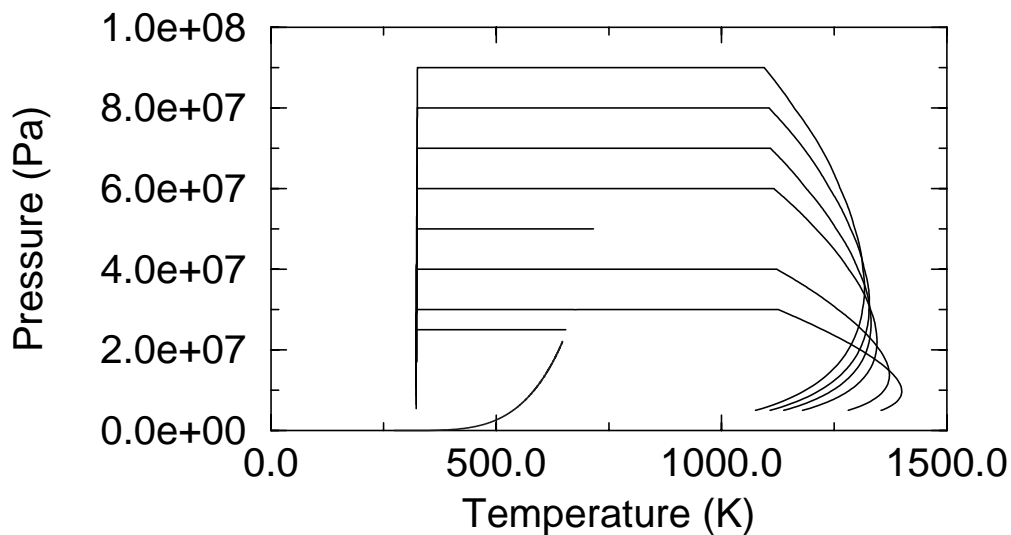


FIGURE 2. Pressure - temperature plots for 'fillpcr' for pressures 90 - 25 MPa (no updates).

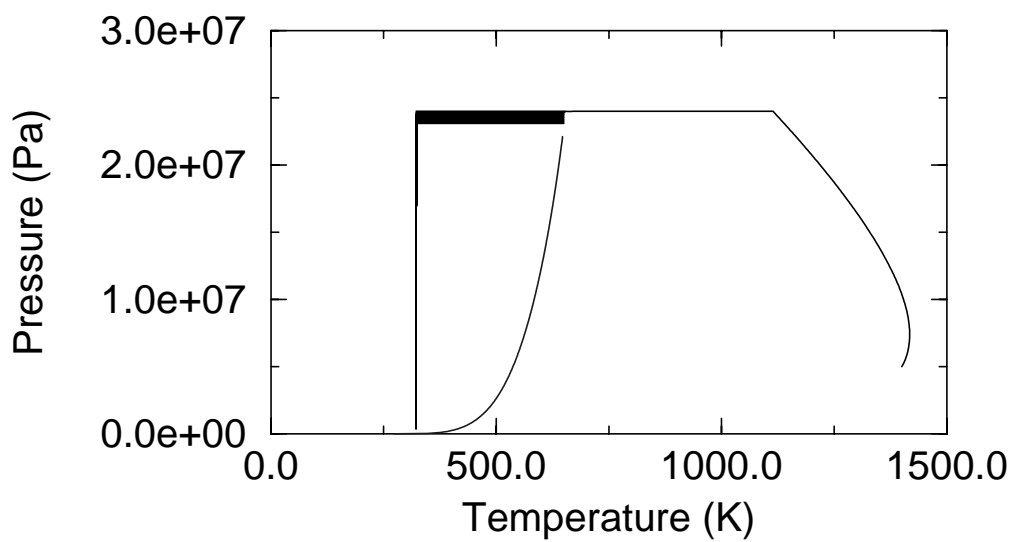


FIGURE 3. Pressure - temperature plots for 'fillpcr' for pressures 24 - 23.1 MPa (no updates).

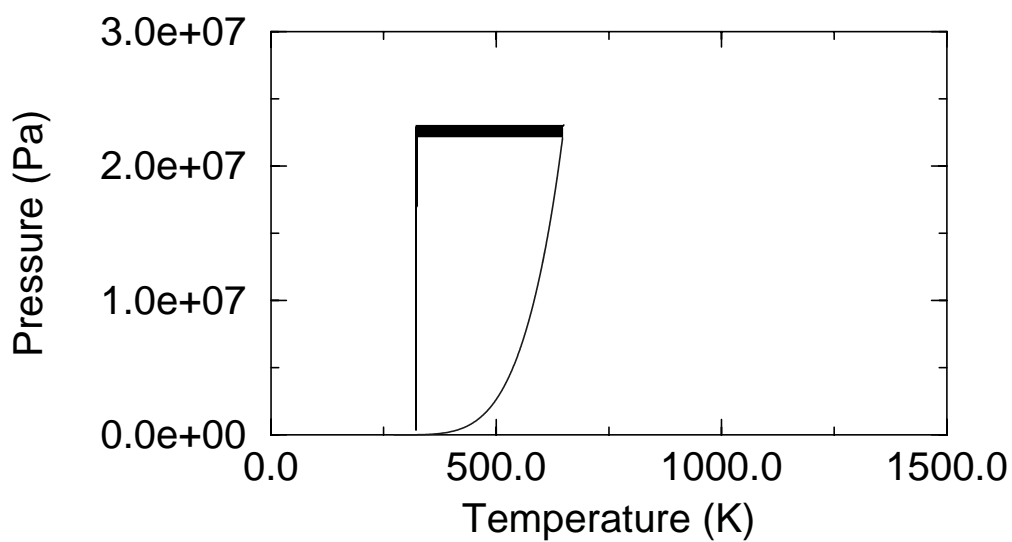


FIGURE 4. Pressure - temperature plots for 'fillpcr' for pressures 23 - 22.2 MPa (no updates).

Figures 5 - 7 show pressure versus temperature plots for the 'fillpcr' calculations with code updates (modifications). Again, the saturation line is also shown.

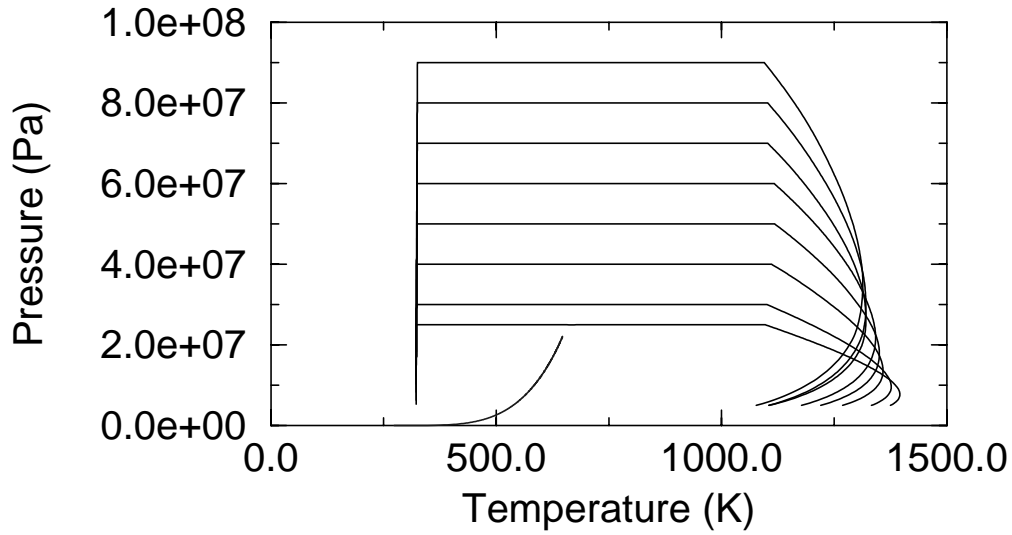


FIGURE 5. Pressure - temperature plots for 'fillpcr' for pressures 90 - 25 MPa (updates).

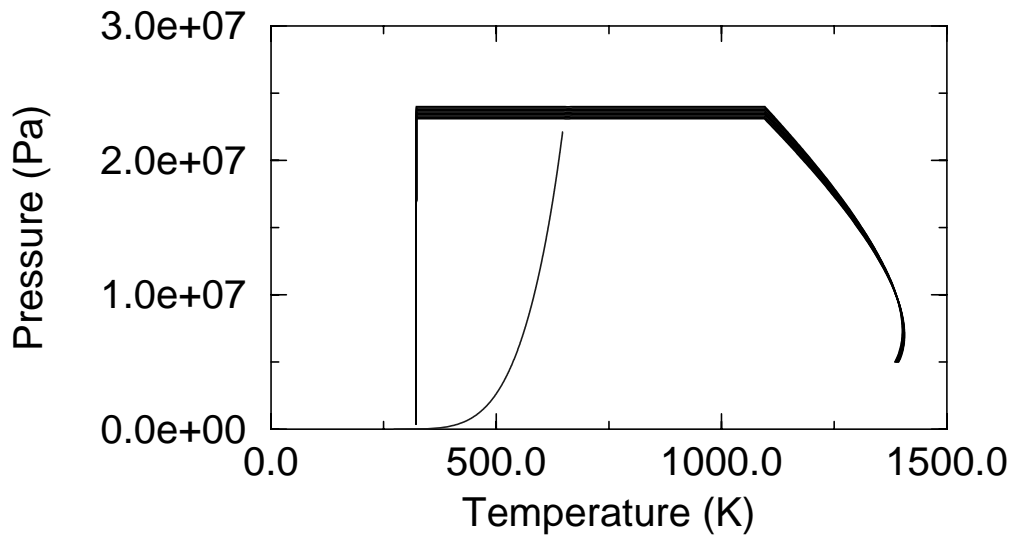


FIGURE 6. Pressure - temperature plots for 'fillpcr' for pressures 24 - 23.1 MPa (updates).

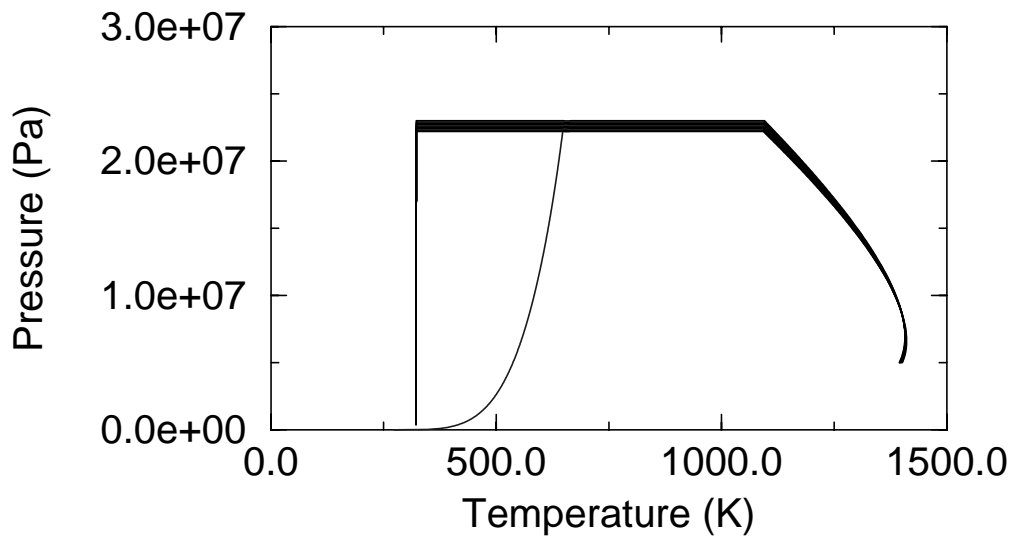


FIGURE 7. Pressure - temperature plots for 'fillpcr' for pressures 23 - 22.2 MPa (updates).

7.0 Summary

This presentation has discussed some of the more generic user problems that have been reported on RELAP5-3D as well as their resolution. The unphysical result problem 1 resulted in code fixes to the choking model. The unphysical result problem 2 resulted in a modified input deck and additional words/equations to the manual. The unphysical result problem 3 resulted in code fixes to the wall heat transfer input processing and manual changes. The code execution failure problem 1 resulted in code fixes to the wall heat transfer and manual changes. The code execution failure problem 2 resulted in codes fixes to the steam-water properties.

8.0 References

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